UNIVERSITY OF BIRMINGHAM

Precision Central Silicon Tracking & Vertexing for the EIC

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University of Birmingham

EIC Detector R&D Meeting | 6-7th July 2016

Proposal

To develop a detailed concept for a central silicon vertex detector for a future EIC experiment, exploring the potential advantages of HV/HR-CMOS MAPS technologies.

WP1: Sensor Development (Gonella, Allport)

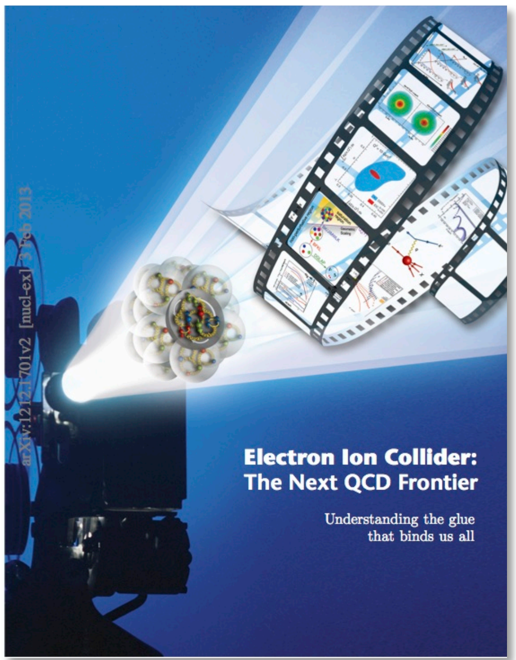
WP2: Silicon Detector Layout Investigations (Jones, Newman)

WP3: Physics Performance Evaluation (Newman, Jones)

Science case

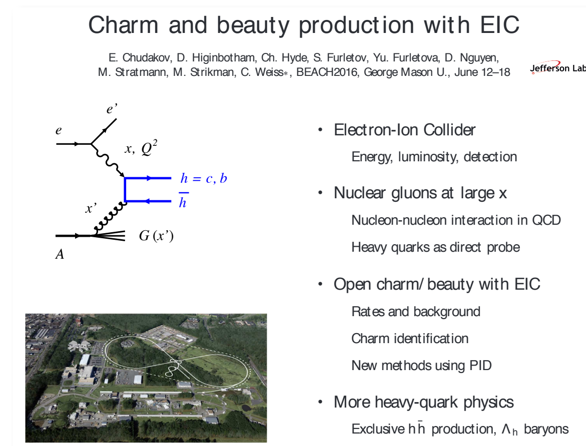
- Improved vertexing capability; emphasis on heavy flavour

EIC promises unprecedented precision in charm (beauty) measurements



A. Accardi et al.,
arXiv:1212.1701

E.C. Aschenauer et al.,
arXiv:1409.1633



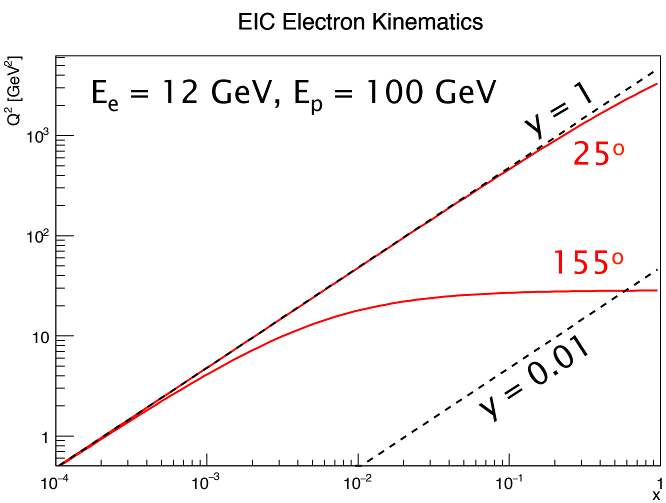
C. Weiss et al.,
JLab LDRD 1601
Nuclear gluons with charm at the EIC

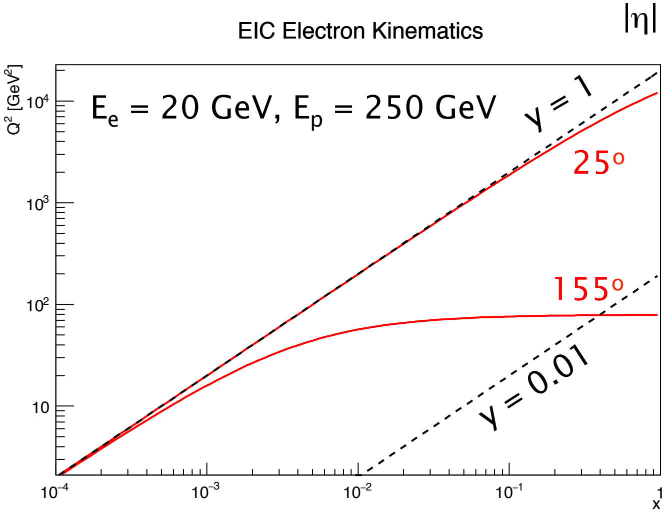
- Improved momentum and angular resolution

May be particularly important for scattered electrons in high Q^2 events

Motivation

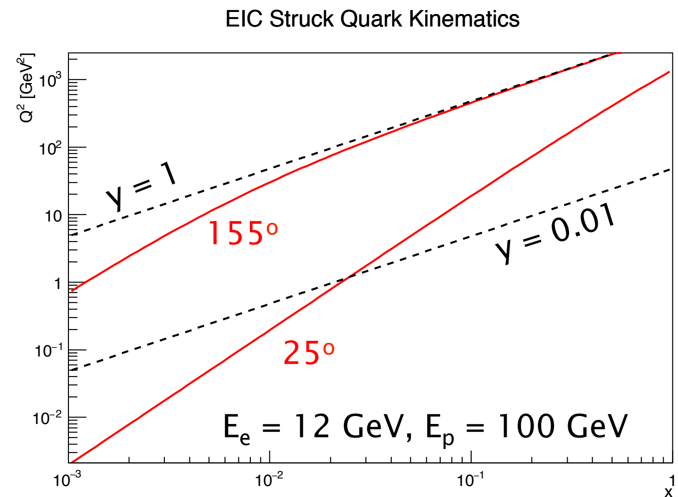
Scattered electron kinematics

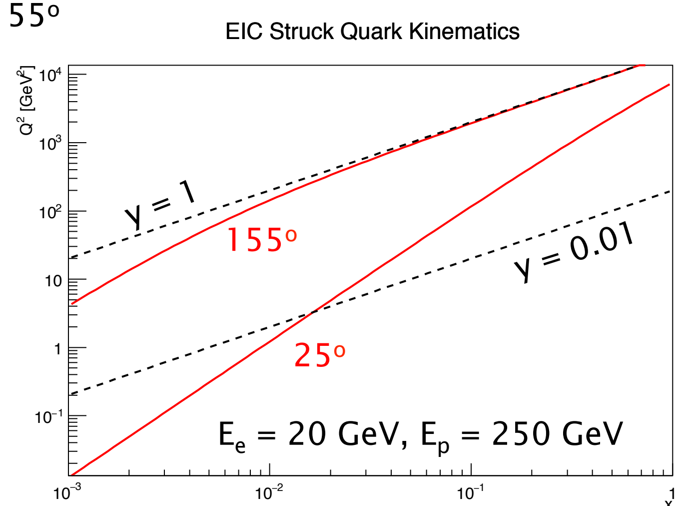




$|\eta| < 1.5 \approx 25° < \theta < 155°$

Struck quark kinematics

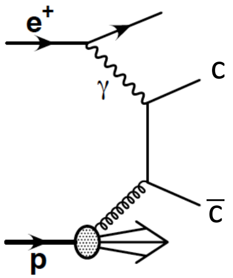




Charm observables

- Importance of charm observables in the updated EIC White Paper

Leading order charm production process is γg fusion



Provides sensitivity to:

I. The gluon contribution to spin of the nucleon

Charm production sensitive to Δg in polarised e+p scattering; complementary to QCD scaling violations observed in inclusive DIS

II. Physics of high gluon densities and low-x in nuclei

The charm structure function F_2^{charm} provides a complementary method for determining the nuclear gluon density in e+A

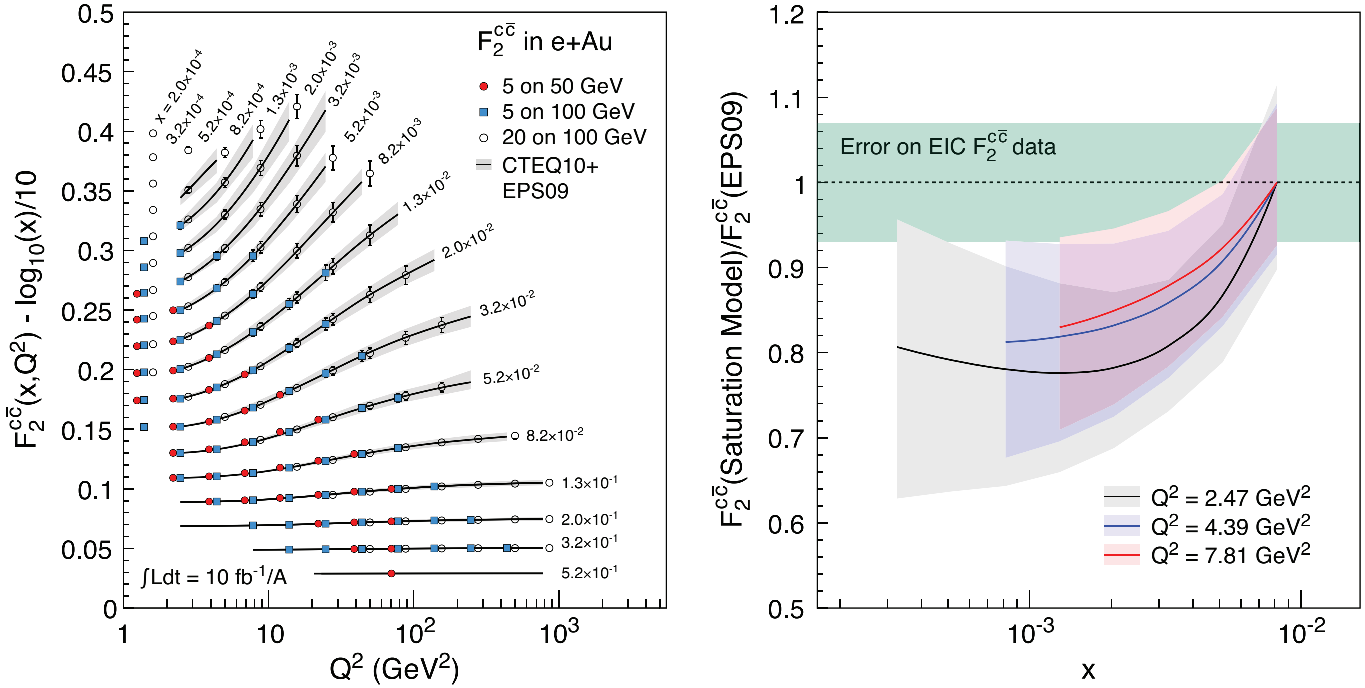
May be particularly sensitive to the onset of gluon saturation

III. Hadronisation and energy loss

Study the nuclear modification of hadronisation and energy loss in cold nuclear matter as a function of quark mass

Expected physics performance

- Physics of high gluon densities and low-x physics in nuclei



Left: Expected precision in F_2^{charm} versus Q^2 in e+Au collisions

Right: Potential to distinguish between saturation and shadowing

- Aim to refine/update these plots with the studies proposed in WP3

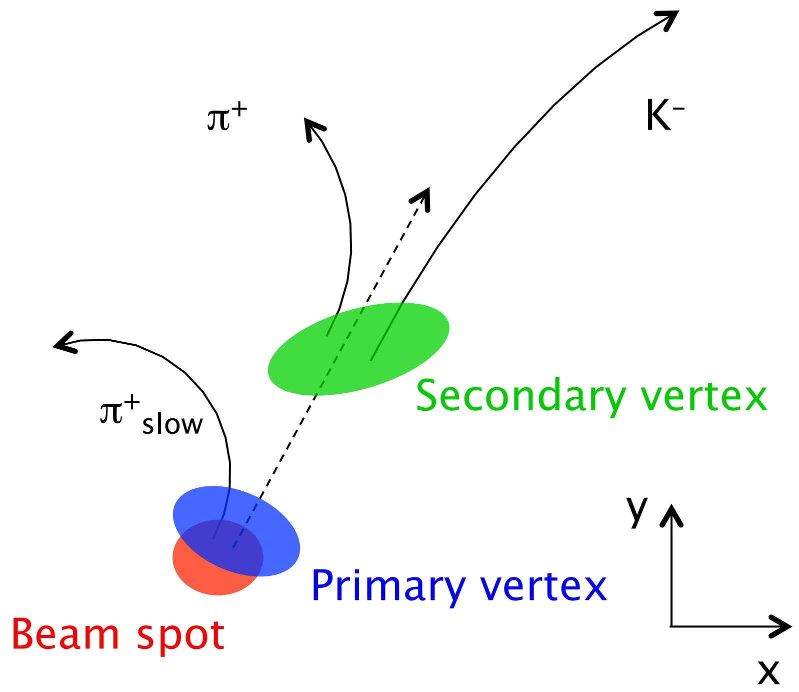
Open charm reconstruction

- Signature is a displaced (secondary) decay vertex

Particle	Decay	b.f.	cτ
D^0	$K^-\pi^+$	(3.9%)	123 μm
D^+	$K^-\pi^+\pi^+$	(9.5%)	311 μm
D^{*+}	$D^0\pi^+_{slow}$	(67.7%)	

Example:

$$D^{*+} \rightarrow D^0\pi^+_{slow} \rightarrow \left(K^-\pi^+\right)\pi^+_{slow}$$

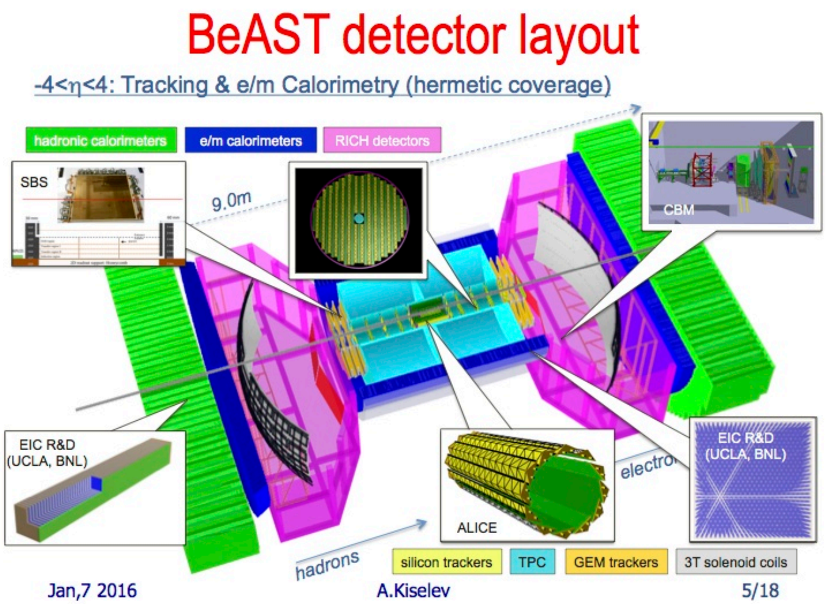


Is it possible to reconstruct the secondary vertex?

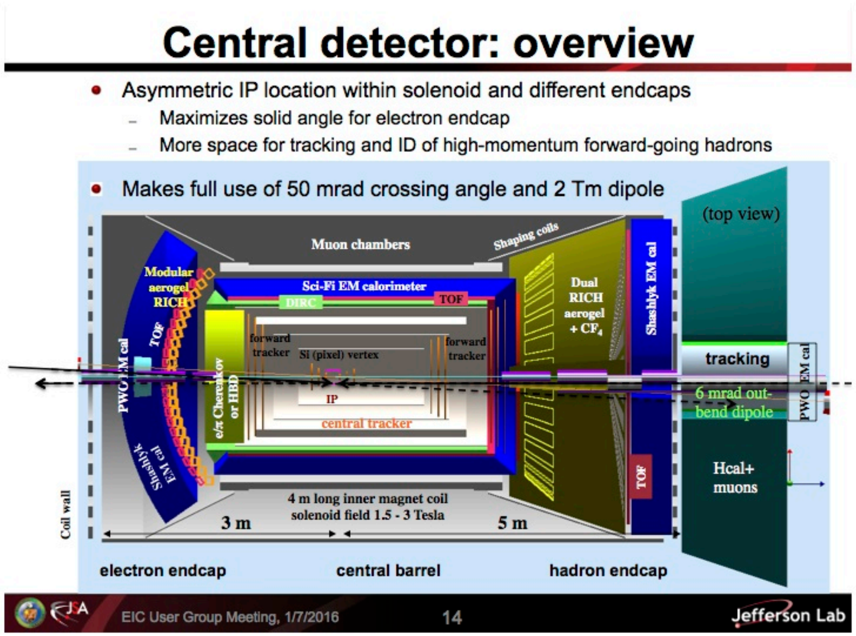
Requires excellent impact parameter resolution in transverse plane

EIC Detector Concepts

- BeAST and Jlab EIC full acceptance detector



Alexander Kiselev



Pawel Nadel-Turonski

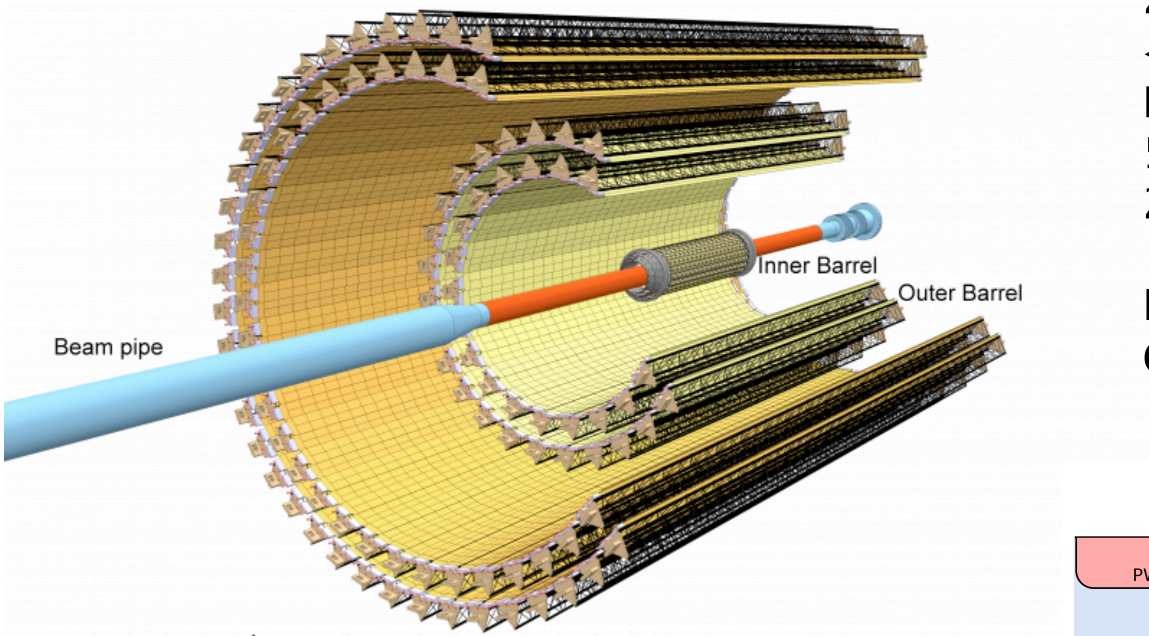
Based on ALICE ITS upgrade
2 x 2 barrel layers
20 x 20 μm^2 pixel pitch
0.3% X_0 per layer

Several technology options, e.g.
Belle II new DEPFET-based pixel SVD

- Propose to optimise vertex detector layout for HF as part of WP2

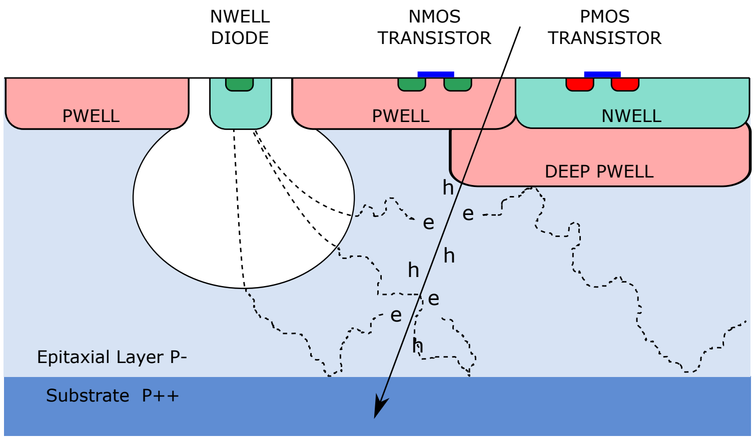
ALICE ITS Upgrade

- A "prototype" EIC vertex detector?



ALPIDE sensor
0.18 μm CMOS Tower Jazz
28 x 28 μm^2 pixel pitch
<2 μs time resolution
Power density < 50 mW cm^{-2}
50 kHz interaction rate (Pb-Pb)
200 kHz interaction rate (pp)

Inner layer thickness = 0.3% X_0
Outer layer thickness = 0.8% X_0



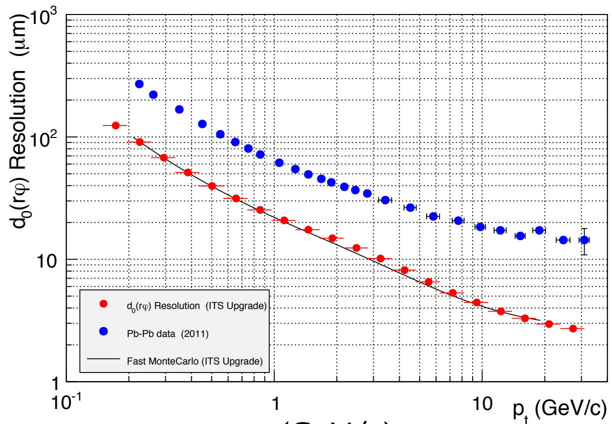
Radiation tolerance
TID: 2.7 Mrad
NIEL: 1.7×10^{13} 1 MeV n_{eq} cm^{-2}
Meets or exceeds requirements of EIC

ALICE ITS performance

- Impact parameter and primary vertex resolution

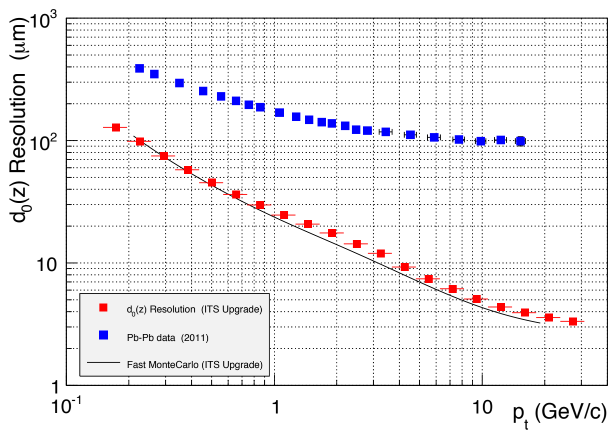
1.)

$\sigma(d_0(r\phi))$ μm



p_T (GeV/c)

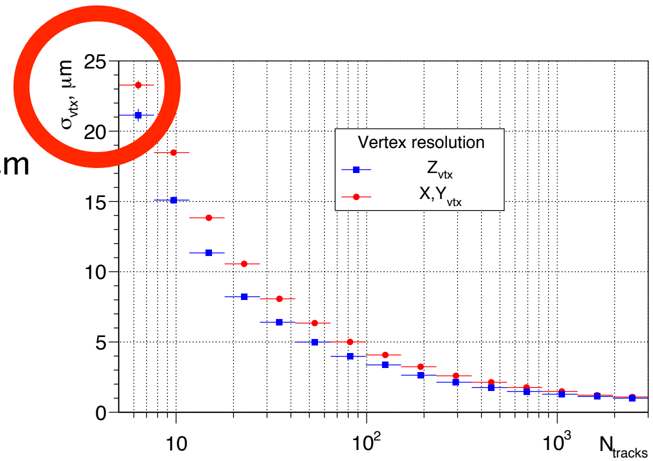
$\sigma(d_0(z))$ μm



p_T (GeV/c)

2.)

σ(vtx) μm



N_{tracks}

1.) impact parameter resolution

σ = (5 ⊕ 22 GeV/p.c) μm

2.) primary vertex resolution

20-25 μm at low multiplicity

Technical Design Report of the Upgrade of the ALICE ITS, J. Phys. G: Nucl. Part. Phys. **41** (2014) 087002)

- Illustrates performance and provides benchmark for this study

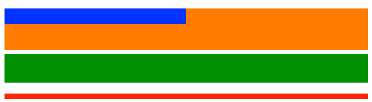
WP1 Sensor Development

- Detector requirements

  1) high granularity and 2) minimal thickness

  Sensor makes "modest" contribution to detector thickness

  (50 μm silicon ≈ 0.05% X_0)



ALICE ITS Inner Layer

Hybrid-IC	0.144% X_0	(55% / Sensor 20%)
Cold Plate	0.100% X_0	(38%)
Space Frame	0.018% X_0	(7%)

- R&D strategy

  Focus on optimal pixel geometry and power requirements

  Maximise Q/C: high signal-to-noise and low power

  Aim of this proposal

  Exploit charge collection by **drift** rather than diffusion NEW

  Explore configuration of collection electrode and pixel size

WP1 Sensor Development

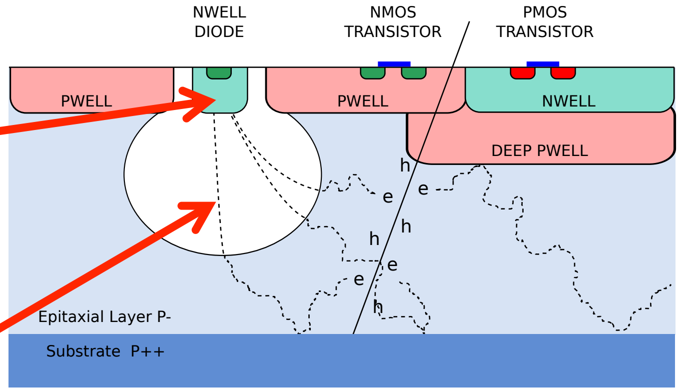
- ALICE experience

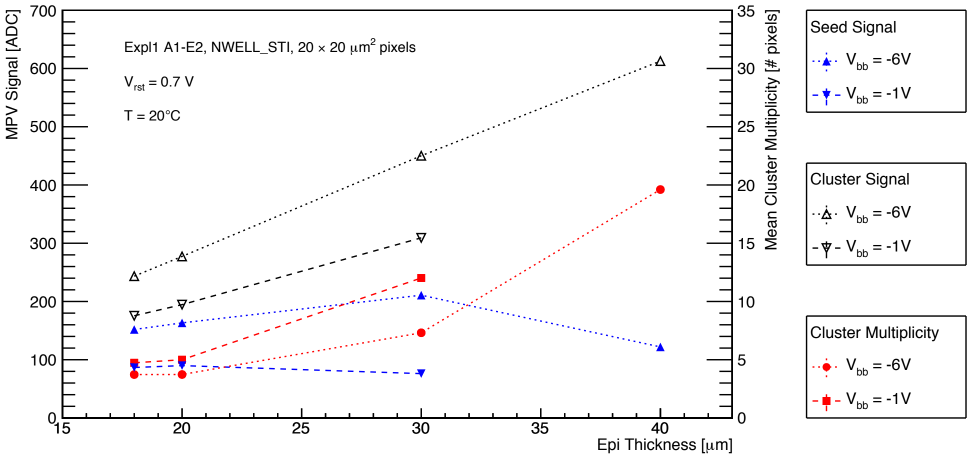
Small collection electrode with separated electronics in deep p-well ➔ small detector capacitance

Possibility to apply a moderate V_{bias} ➔ charge collection by drift in depleted volume

Thicker epitaxial layers yield larger Q, but the cluster size is larger due to diffusion.

Larger depletion volume desirable to maximize seed signal while keeping low cluster multiplicity.





J. Phys. G: Nucl. Part. Phys. 41 (2014) 087002

WP1 Sensor Development

- Sensor development in this proposal

New development with Rutherford Appleton Laboratory and TowerJazz.

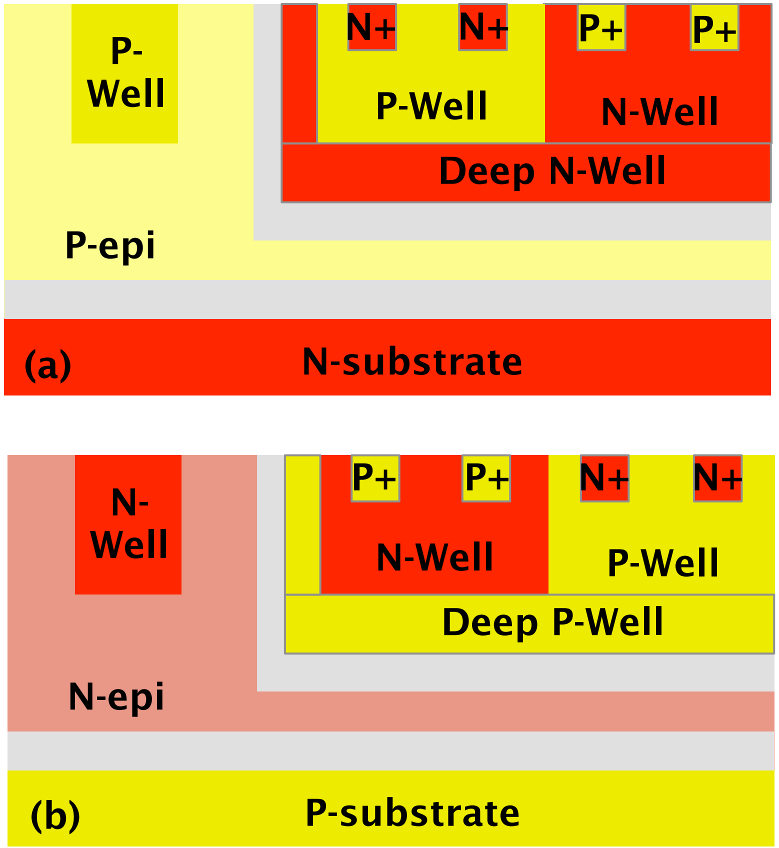
Add junction on back side of sensor

1) larger depletion volume,
2) small collection electrode and
3) potentially very low capacitance.

Two options: invert a) substrate or b) epitaxial layer

Option b) proposed by us to exploit the benefit of using an n-type collection electrode:

- Lower diffusion for a given V_{bias}
- Faster charger collection, less charge spread at the electrode
- (Improved radiation hardness)



Birmingham-RAL-Sussex
Candidate EIC sensor

NEW

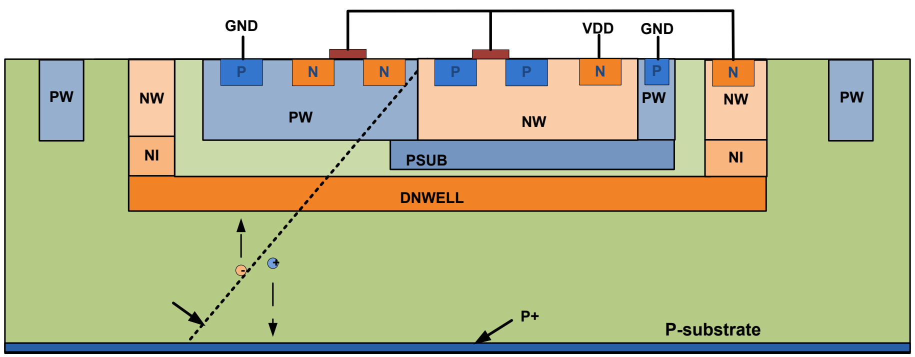
WP1 Sensor Development

- Possibility to explore options with LFoundry technology

  150 nm CMOS quadruple well process

  Access to chip design and MLM run via RD50 collaboration

  Possibility to design large electrodes with isolated electronics



N. Wermes, AIDA2020 1st annual meeting, Hamburg, June 2016

larger electrode = larger drift volume ➔ larger signal

Being explored for HL-LHC for its radiation hardness

Larger capacitance means higher noise and higher power

Still possible to achieve high signal-to-noise? Can novel powering schemes mitigate power increase?

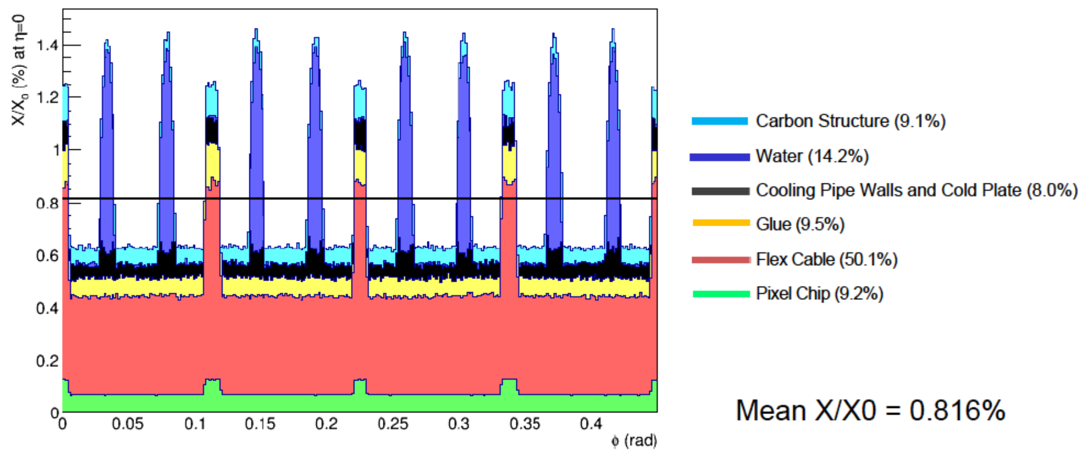
Timeline: Call for interest sent out to RD50 institutes; first meeting to discuss layouts at end of summer; submission expected next year.

WP1 Sensor Development

- Material budget considerations

J. Phys. G: Nucl. Part. Phys. 41 (2014) 087002

Cables to bring in power and cooling to extract it dominate the material budget of trackers in HEP



ALICE ITS Outer Layer

Counter-measures: low power FE + power distribution at low current and high voltage (DC-DC conversion, serial power)

Serial power distribution could be considered to lower cable material in active area, following the baseline design for the ATLAS and CMS pixel detectors at the HL-LHC

See: Laura Gonella, Developments for serial power appilcations, ACES Workshop

https://indico.cern.ch/event/468486/contributions/1144360/attachments/1239152/1822525/20160308-ACES.pdf

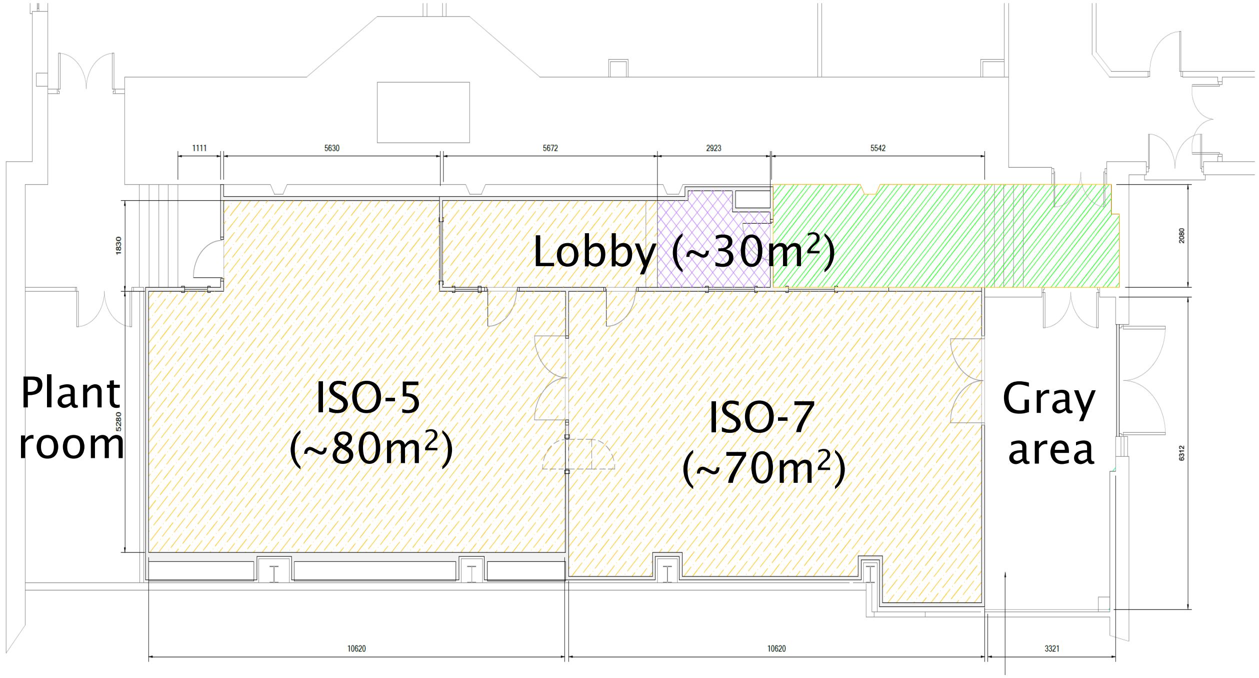
WP1 Facilities

- Track record: ATLAS SCT (current) and ITK strips (phase 2 upgrade)
- New Instrumentation Laboratory

  Investment in new ~200 m^2 laboratory; available from July 2016

  New academic appointments: Phil Allport, Laura Gonella, Steve Worm

  Expanding manufacturing capability and growing new R&D in MAPS



Birmingham Instrumentation Laboratory for Particle physics and its Applications

WP1 Facilities

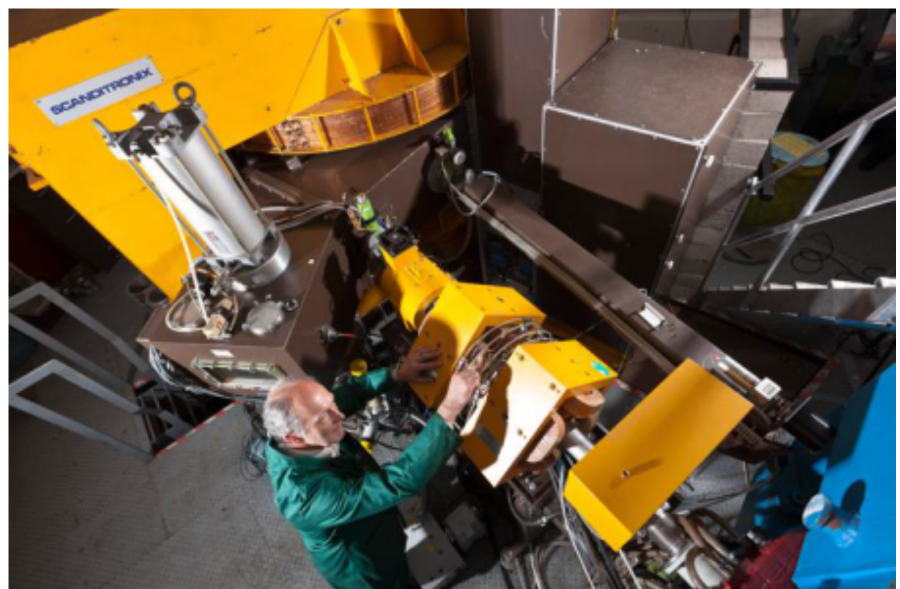
- Instrumentation Laboratory

Equipment:

Hesse & Knipps BondJet 820 automatic wire bonder
Delvotec 5430 semiautomatic table top wire bonder
Dage 4000 wire-pull and shear strength tester
Dima Dotmaster with the DD-5097 upgrade
Cascade Microtech REL 4800 manual probe station
Cammax Precima DB600 die bonder pick and placer
2 x Keithley 2410
Plus inspection microscopes, electrical test equipment, N2 storage, environmental chamber, precision scales, ...
We are also purchasing:
Cascade Summit12000B semi-automatic probe station
TCT Laser system
X-ray flourescence tube and targets
Keithley 2410
Keithley 6517B
4285A Precision LCR Meter

WP1 Facilities

- Birmingham MC40 Cyclotron
  - Primarily used for medical radioisotope production
  - An irradiation facility for particle physics was commissioned in 2013
  - 27 MeV protons (max 40 MeV), 1 cm^2 beam spot with 1 μA beam current
  - Scanning and low temperature irradiation capability
  - Delivers HL-LHC doses within a single day of operation



WP1 Sensor Development

- MAPS prototype structures with TowerJazz foundry

  UK STFC-funded R&D project; Birmingham-RAL-Sussex collaboration

  Start date: 1st June 2016; 2 years development programme

Development towards a Reconfigurable Monolithic Active Pixel Sensor in Radiation-hard Technology for Outer Tracking and Digital Electromagnetic Calorimetry

P.P. Allport[1], D. Das[2], L. Gonella[1*], S.J. Head[1], K. Nikolopoulos[1], S. McMahon[2], P.R. Newman[1],

P. Phillips[2], F. Salvatore[3], R. Turchetta[2], G. Villani[2], N.K. Watson[1], F. Wilson[2], Z. Zhang[2]

1) The University of Birmingham

2) Rutherford Appleton Laboratory, STFC

3) The University of Sussex

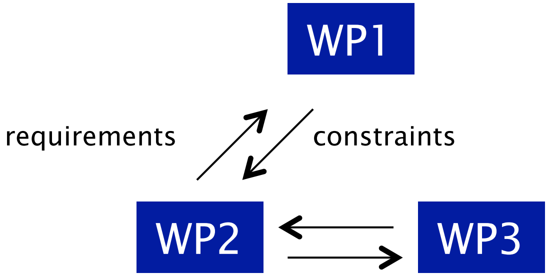
  TCAD simulations are starting and preliminary specifications for active pixels are being defined

  Possibility to have test structures with different pixel sizes, collection electrode geometry and implant

  Expect prototypes on timescale of ~ 1 year

WP2 and WP3 summary

- WP2 – Silicon Detector Layout Investigations
  - Optimise vertex detector layout for heavy flavour studies
  - Explore sensitivity to spatial resolution and detector thickness
  - Characterise performance with single tracks and open charm decays
  - Aim to optimise # layers and radial distances wrt outer tracking
- WP3 – Physics Performance Evaluation
  - End-to-end simulations of HF processes with realistic detector model
  - Initial focus on F_2^{charm} and F_2^{beauty} in e+A



- Opportunities for collaboration
  - Synergy with JLab LDRD 1601 (C. Weiss et al.)
  - eRD16 – MAPS for forward and backward tracking
  - eRD6 – Tracking and PID consortium

Scope and deliverables

- Scope and deliverables

  Two year R&D project

  Proposed deliverables in the first year:

  - WP1: Specification and submission of test structures in Tower Jazz
  - WP1: Specification and submission of test structures in LFoundry
  - WP1: TCAD simulations to optimise pixel geometry and aspect ratio
  - WP1: Initial characterisation of Tower Jazz sensor properties
  - WP2: Study of track momentum resolution and impact parameter resolution with different assumptions on spatial resolution of pixel hits and number of tracking layers
  - WP3: Apply e+p or e+A Monte Carlo models for heavy flavour processes in EIC simulations to begin studies of open charm and beauty production

Resources summary

Jones (0.1 FTE), Gonella (0.2 FTE), Newman (0.1 FTE) and Allport (0.05 FTE)

Test structures from Tower Jazz foundry run

PhD student (from October 2017)

Computing resources

Access to MC40 cyclotron for early irradiation studies

Requested

One full-time postdoc, approximately £103k, including overheads

Travel to and from UK partners (RAL) £1k

Travel to and from the US to attend EIC meetings £6k

Licenses for TCAD £1k

Contribution to 2016 RD50 L-Foundry run £4k

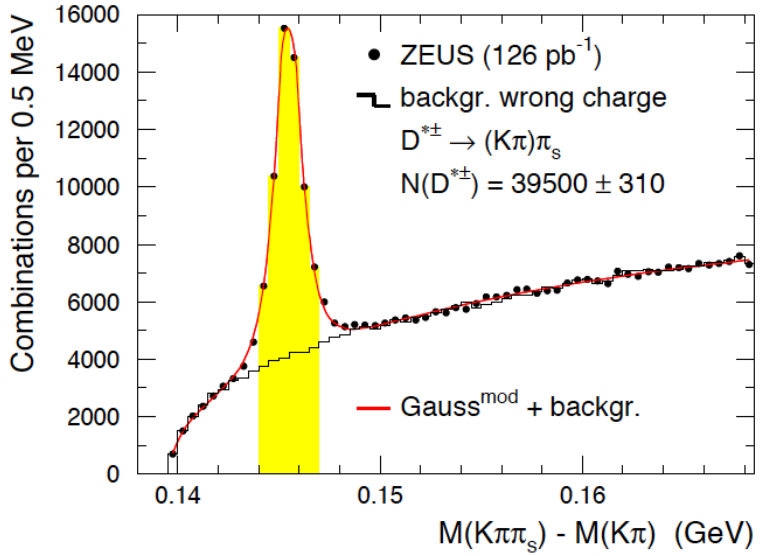
Total: £115k (approx. $150k)

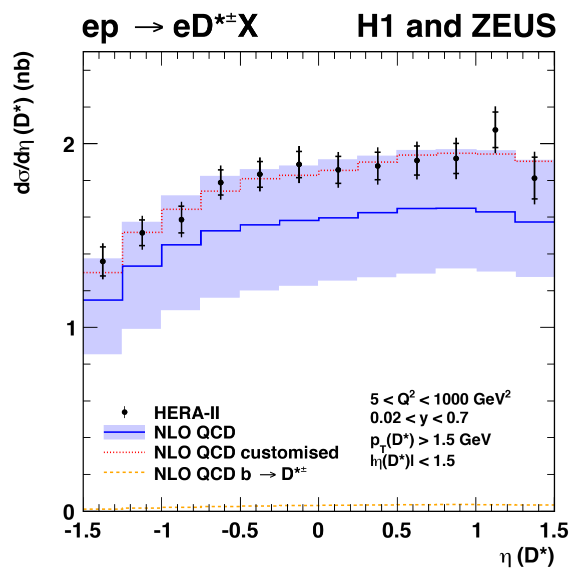
Backup slides

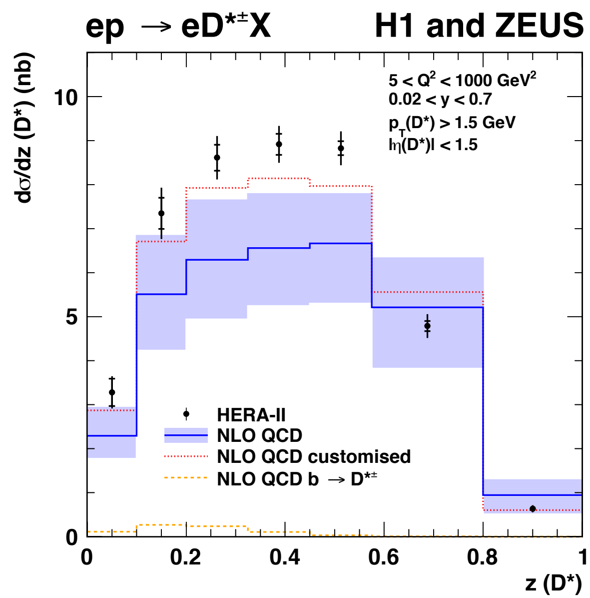
Track record

- Prof Peter Jones – Head of the Birmingham Nuclear Physics research group. Background in relativistic heavy ion collisions. Past member of the STAR collaboration (Strangeness Working Group Convenor 1996-2001). Member of the ALICE collaboration (Editorial Board member since 2015).
- Dr Laura Gonella – Lecturer in silicon detector technologies. Particular expertise in CMOS pixel sensors. Joined the University of Birmingham in 2015 from the University of Bonn. Currently co-leads the ATLAS ITK Strip Tracker Upgrade ASICs group.
- Prof Paul Newman – Head of the Birmingham Particle Physics research group. Background in deep inelastic scattering. Member of the H1 collaboration (Physics Coordinator 2001-4) and the LHeC Study Group (Coordination Group and Low-x Working Group Convenor).
- Prof Phil Allport – Joined the University of Birmingham in 2014. Director of the Birmingham Instrumentation Laboratory for Particle Physics and its Applications. ATLAS Upgrade Coordinator 2011-15. Leads the Birmingham RD50 group and AIDA-2020 Transnational Access contact for the MC40 cyclotron.

Experience from HERA







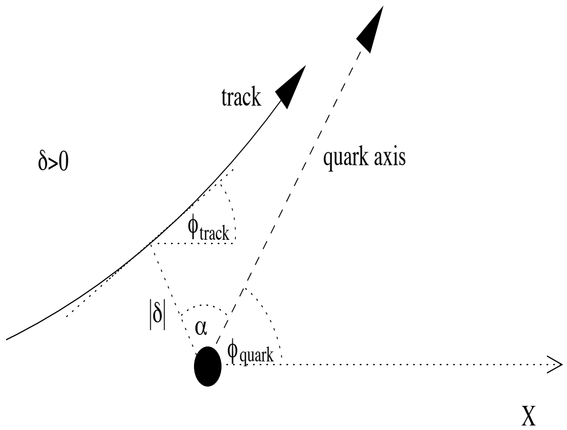
$D^* \to D^0 \pi_s \to K\pi\, \pi_s$ by far the most productive charm channel at HERA

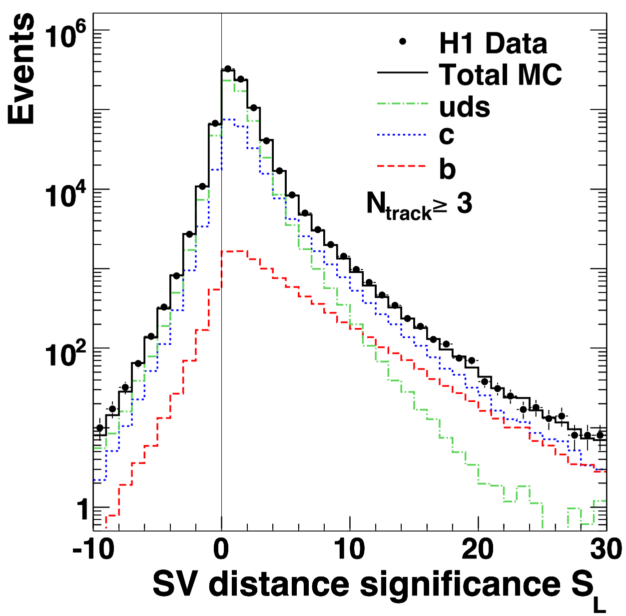
"Slow" pion, π_s has low pT ~ 100 MeV → vital
To maintain charged particle efficiency to low pT

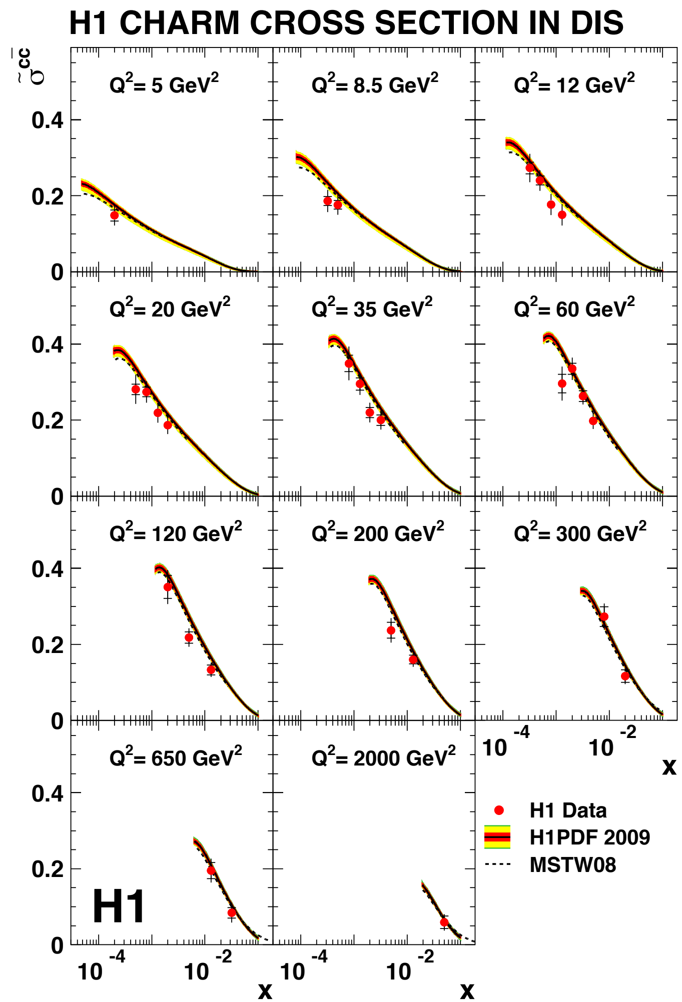
Width of D* peak highly dependent on charged track resolution → strong motivation to optimise now

Physics not perfectly understood even for ep →
Rich programme at EIC …

HF Results from H1







Gluon polarisation results